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(71) Applicant : AICHI STEEL WORKS, LIMITED
1, Wanowari Arao-cho Tokai-shi
Aichi 476 (JP)
Applicant : KOYO SEIKO KABUSHIKI KAISHA
5-8 Minamisenba 3-chome
Chuo-ku, Osaka (JP)
Applicant : NIPPONDENSO CO., LTD.
1, Showacho 1-chome
Kariya-shi Aichi-448 (JP)

(72) Inventor : Takata, Yatsuka
6-8, Tsutsujigaoka 3-chome
Chita, Aichi (JP)
Inventor : Muroga, Akira
163, Komegase-cho, Kita-ku
Nagoya, Aichi (JP)
Inventor : Wakikado, Yoshihiro
26-7, Aza Hazama, Kanazawa
Chita, Aichi (JP)
Inventor : Ooki, Takao
1-2-14, Minamikasuya
Chita, Aichi (JP)
Inventor : Goto, Masao
2-13-1, Asahigaoka
Kashiwara, Osaka (JP)
Inventor : Tazumi, Hazime
4-12-202, Higashiyamamotoshinmachi
4-chome
Yao, Osaka (JP)
Inventor : Hoshino, Teruo
3-61-11, Kamio-cho
Yao, Osaka (JP)
Inventor : Kitamura, Masayuki
1-9-1-B701, Sonenishimachi
Toyonaka, Osaka (JP)
Inventor : Kawaguchi, Toshihiro
2-13-1, Asahigaoka
Kashiwara, Osaka (JP)
Inventor : Natsume, Yoshitaka
91-12, Nishida, Noda-cho
Kariya, Aichi (JP)
Inventor : Mizutani, Akihiro
1-177, Chugo, Nakagawa-ku
Nagoya, Aichi (JP)

(74) Representative : Hale, Peter et al
Kilburn & Strode 30 John Street
London WC1N 2DD (GB)

(54) Bearing steel.

(57) A bearing steel having long rolling life comprising, by weight, 0.65 to 0.90% of C, 0.15 to 0.50% of Si, 0.15 to 1.0% of Mn and 2.0 to 5.0% of Cr, and the balance of Fe. Austenite grain size can be prevented from becoming coarser to make hardening in high temperature possible by further adding 0.0090 to 0.0200% of N, one or more of 0.010 to 0.050% of Al, and 0.005 to 0.500% of Nb as optional elements to the steel. Further, rolling fatigue life can be improved by further adding one or more of 0.20 to 0.50% of Ni, 0.10 to 2.00% of Mo and 0.05 to 1.00% of V as optional elements, and machinability can be improved by further adding one or more of 0.02 to 0.05% of S, 0.005 to 0.10% of rare earth elements, 0.02 to 0.30% of Pb, 0.0005 to 0.0100% of Ca, 0.001 to 0.200% of Bi, 0.005 to 0.20% of Se and 0.005 to 0.100% of Te in the steel as optional elements.

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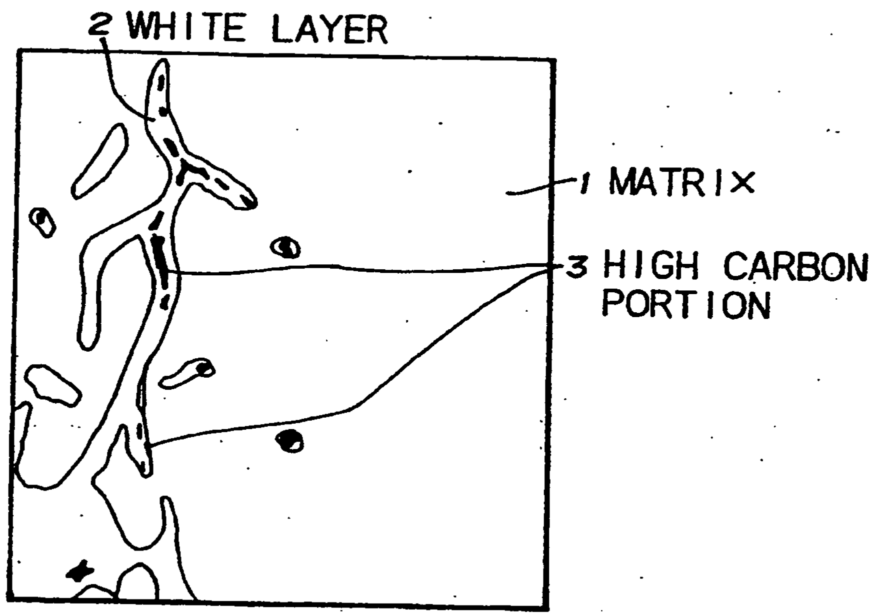
FIG.2



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The present invention relates to a bearing steel for use in ball bearings and/or roller bearings (hereinafter referred to as "rolling bearings") of engines and auxiliary equipment such as alternators driven by, for example, of automobile engines. The invention is particularly suited to situations involving vibration and impact load, as well as for use in rolling and sliding components generally.

As a material for bearing rings and balls and/or rollers (hereinafter referred to as "rolling elements") in rolling bearings, high-carbon chromium bearing steels (in particular JIS SUJ2) have been used most generally. In addition, various other materials are also used corresponding to the varied working conditions for rolling bearings. For instance, case hardened steels (for example, SAE 5120) which have been carburizing hardened and tempered for improving their toughness are used for bearings undergoing impact loads.

For engines and auxiliary equipment such as alternators driven by, for example automobile engines, reduction of the size and the weight, as well as improvement of performance have progressed vigorously in recent years. Attendant to this the size and the rated speed of rotation of the rolling bearings used therefore have been improved. This considerably increases vibration and impact loads exerted on the rolling bearings and elevates the working temterature of the bearing, resulting in the problem of peeling which occurs in a short period of time in the rolling bearing made of the prior art steels described above. This makes the bearing unusable. For instance, in automobile engine-driven alternators vibrations transmitted from driving belts interconnecting therebetween are always exerted on the bearings in addition to the impact loads caused by an uneven road surface transmitted through the wheels of the moving automobile.

It is apparent that reduction of the size and the weight and the improvement of the performance of the engines or the auxiliary equipment will continue to be sought under the increasing requirement for improved fuel consumption in automobiles. Accordingly, there is a keen demand for the development of bearing steels capable of having durability and a long life under high speed rotation, vibration and impact loads.

For the study directed to the resolution of the foregoing subject, the present inventors have at first investigated factors that are attributable to the reduction of the durability and life of the bearing caused by high speed rotation. As a result, although the shortened life span the bearing seems to be caused by peeling, it has been found that phenomena different from those considered so far are present in the peeling process.

At first, when a cross sectional micro structure was observed under the rolling surface of a bearing that suffered from peeling during high speed rotation in a short period of time, a metallic structure which is less corrosive and appeared white (hereinafter referred to as "white layers"), different from a matrix (matrix phase), was formed under the rolling surface near a position where the maximum shear stress occured.

Fig. 1 shows an optical micrograph of the micro structure along the cross section containing the white layers.

when the hardness of the white layer portion and the matrix at the periphery thereof was measured by a micro Vickers hardness tester, it was found that the hardness of the matrix was about HV 750, whereas the hardness of the white layer was HV 1100 to 1300. Accordingly, the white layer portion is much harder than the matrix portion.

From the results described above, it has been estimated that the reason the durability life of the bearing is shortened in high speed rotation, is that the white layers are formed in a position near the portion where the maximum shear stress occurs and that the white layer is hard and brittle. Accordingly, crack form at an early stage by repeated application of shear stresses. These cracks easily develop into the matrix to cause peeling.

However, such white layers which shorten the life span of the bearing are not observed in the usual durability life test for bearings and it is therefore considered that vibrations and impact loads have a great influence on the factors reducing the durability life of the bearing due to the occurence of the white layers. A test was conducted for confirming this consideration.

A ball bearing JIS B 1512 (6303) (17 mm in inner diameter, 47 mm in outer diameter) was prepared from two kinds of materials shown in Table 1, with the inner and the outer rings being made of an identical material, and then subjected to a heat treatment specified in the middle column of the table so as to attain the hardness shown in the right column of the table. Then, a rotational durability life test was made of the bearing specimens by applying loads by two static and dynamic methods as shown in Table 2. In the static load test, the bearing specimen is mounted in a durability life tester and rotated continuously under a static load. On the other hand, in a dynamic load test, a durability life tester is disposed on a vibration bed and the bearing specimen subjected to a continuous rotation test while applying a static load to the bearing specimen and applying vibrations to the entire testing machine. The rotational durability life test was conducted twice for each of the materials and each of the test conditions and the results are shown in Table 3.

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Table 1

Kind of specimen	Material	Heat treatment	Hardness (HRC)
TA	JIS:SUJ2	Hardening—tempering	61~62
TB	SAE:5120	Carburizing—hardening, tempering (effective hardening depth=0.7~1.0mm)	Surface hardness 61~62

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Table 2

Test method	Static load test	Dynamic load test
Load $= \frac{\text{Bearing load (static load)}}{\text{Rated dynamic load}}$	0.22	
Rotational speed (inner ring rotation)	18,000 rpm	
Lubrication	Grease sealed	
Calculated life (not considering vibration)	87 hr	
Acceleration of vibration	0 (not added)	10 G (on vibration bed)

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Table 3

Kind of specimen	Static load test			Dynamic load test		
	specimen No.	rotational speed (hr)	Content of life	specimen No.	rolling life (hr)	Content of life
TA	TA 1	1000	With interruption, no abnormality	TA 3	43	Peeling, with white layer
	TA 2	1000	With interruption, no abnormality	TA 4	61	Peeling, with white layer
TB	TB 1	1000	With interruption, no abnormality	TB 3	189	Peeling, with white layer
	TB 2	1000	With interruption, no abnormality	TB 4	202	Peeling, with white layer

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As a result of the test, it has been found that peeling occurred in none of the bearing specimens even after 1000 hours of continuous rotation in the static load test, giving no problem for the durability life time. However, in a dynamic load test in which vibrations are superposed on the static load test, it has been found that peeling occurred after only 43 hours and 61 hours in the bearings made of steel according to JIS SUJ 2 and in 189 hours and 202 hours in the bearings made of SAE 5120 and case hardened steel according to SAE 5120, remarkably reducing the durability life of the bearing.

When the microstructure of the metal positioned under the rolling surface of the specimen showing reduced durability life in the dynamic load test was observed, it was recognised that white layers like those in Fig. 1 are created.

When the distribution of the carbon (C) concentration in the microstructure in which the white layer exists was analyzed by EPMA (electron probe micro analyzer), it has been found that the carbon (C) concentration was higher in the white layer portion than in the matrix portion. Fig. 2 schematically shows the result of the investigation by EPMA for the carbon concentration distribution in the white layer and in the peripheral portion thereof, in which it is clearly shown that the carbon concentration is higher in the white layer 2 than in the matrix 1. It has been further confirmed that within the white layer 2, a portion showing higher carbon concentration (high carbon portion) 3 than that in the white layer 2 is present.

It is considered that the reason why the white layer portion has higher carbon concentration is because the carbon atoms are diffused and condensed in that portion. Since the diffusion of the carbon atom is induced by stresses, it is considered that loading repeating stresses on the bearing specimen due to vibration promotes the stresses-induced diffusion of the carbon atoms, to promote the condensation of carbon in the white layer portion. Further, micro strains are accumulated in the microstructure positioned under the rolling surface due to the loading of the repeating stresses and the carbon atoms are bonded there due to the accumulated strains. That is, the carbon atoms are diffused and bonded in the metallic structure located at a position under the rolling surface where the maximum shear stress occurs by the repeated impact stresses. Consequently, the white layers having extremely high hardness and which are less corrosive come into existence. Then, by the application of the repeated impact loads, cracks are formed from the very hard and brittle white layers, which are propagated and develop into the matrix, causing early peeling.

A primary object of the present invention is to provide a bearing steel having a long durability life even in a case where it is used under vibrations and impact loads due to high speed rotation.

In view of the foregoing object and with the consideration that inhibition of the formation of the white layers is necessary for improving the durability life of the bearings, the present inventors have aimed at the suppression of carbon diffusion and improvement of the matrix strength. Then, as a result of an investigation for a relationship between the content of carbon and other alloying elements and the diffusion rate of carbon, it has been found that lowering of the carbon content and increase of the chromium concentration are effective means for retarding the diffusion rate of carbon. Further, alloy designing has been conducted also for alloy ingredients in order to provide sufficient mechanical strength to use as a bearing and, further, to minimize carbides or non-metallic inclusions which are harmful to the rolling bearing steel.

According to the present invention there is provided a bearing steel comprising, by weight, 0.65 to 0.90% of C, 0.15 to 0.50% of Si, 0.15 to 1.00% of Mn, 2.00 to 5.00% of Cr, and optionally, a member or members selected from the group consisting of 0.20 to 0.50% of Ni, 0.1 to 2.0% of Mo and 0.05 to 1.00% of V, the remainder being Fe and inevitable impurities.

Since the bearing steel described above has a relatively high Cr content, it is necessary to increase the quench hardening temperature above that for the usual bearing steels (JIS SUJ2) for attaining improved mechanical properties. Further, while bearing steels have been used generally as materials for rolling bearing units so far, they have been used also for automobile parts such as rolling or sliding components such as constant velocity joints (CVJ's) and cam faces along with improvements in automobile parts in general in recent years. Such automobile parts include those having a greater size than rolling bearings, and sometimes require longer heating times necessary for the quench hardening.

However, if the quench hardening temperature is elevated or the time necessary for quench hardening is prolonged, there may be a risk that the austenite crystal grains become coarser, reducing the toughness after the heat treatment. This may lead to a reduction of the contact rolling fatigue life and offset the advantageous effect attained by the steel according to the present invention which is made as a result of the study described above.

It is, accordingly, another object of the present invention to provide a bearing steel capable of attaining the characteristics of the bearing steel of the prior statement as far as possible without making the crystal grains coarser even under an increased quench hardening temperature.

Also according to the invention, the bearing steel described above comprises, by weight, 0.65 to 0.90% of C, 0.15 to 0.50% of Si, 0.15 to 1.00% of Mn, 2.0 to 5.0% of Cr and 0.0090 to 0.0200% of N, and a member or

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members selected from the group consisting of 0. 010 to 0. 050% of Al and 0.005 to 0.50% of Nb the remainder being Fe and inevitable impurities. One or more of 0. 20 to 0. 50% of Ni, 0.10 to 2.00% of Mo and 0.05 to 1.00% of V may further be added as an optional element or elements.

Further, in course of manufacturing a rolling bearing from the bearing steel, it is always necessary to cut the steel material at the stage of working it into an intermediate shape or final shape (ball, roller or race). Further, the cutting process is also applied in the course of manufacturing rolling or sliding components for automobiles such as CVJ's(constant velocity joints)and face cams. Since automobile parts have to be generally mass-produced at a reduced cost, machinability of the material is an important factor in quality.

In the course of cutting steel materials, annealing is usually applied previously to reduce the hardness. However, since the bearing steel has a high carbon content, excellent machinability can not be obtained even after applying sufficient annealing, which results in the problem of worsening the production efficiency of bearings or parts in the cutting step. In particular, since the above-identified bearing steel in accordance with the present invention has a relatively high Cr content, the hardness after annealing is somewhat higher and it is desired to improve the machinability.

A further object of the present invention is to provide a bearing steel capable of improving the efficiency for the cutting step, which would otherwise constitute a barrier in the bearing manufacturing step without offsetting the long durability life of the bearing steel. The bearing steel as described above comprises, by weight, 0.65 to 0.90% of C, 0.15 to 0.50% of Si, 0.15 to 1.00% of Mn, 2.0 to 5.0% of Cr and a member or members selected from the group consisting of 0.020 to 0.050 of S, 0.005 to 0.10% of rare earth element, 0.02 to 0.30% of Pb, 0.0005 to 0.0100% of Ca, 0.001 to 0.200% of Bi, 0.005 to 0.20% of Se and 0.005 to 0.100% of Te, the remainder being Fe and inevitable impurities. Further, a member or members selected from the group consisting of 0.20 to 0.50% of Ni, 0.10 to 2.00% of Mo and 0.05 to 1.00% of V may be incorporated as optional element or elements.

Various other objects, features and attendant advantages of the present invention will be more fully appreciated as the same becomes better understood from the following detailed description when considered in connection with the accompanying drawings wherein:

Fig. 1 is an optical micrograph showing a cross sectional micro structure positioned under a rolling surface of a bearing that causes peeling in a short period of time due to high speed rotation; and

Fig. 2 is a schematic view showing the result of EPMA analysis for the distribution of the carbon concentration in the white layer and the matrix.

The present invention relates to a bearing steel comprising, by weight, 0.65 to 0.90% of C, 0.15 to 0.50% of Si, 0.15 to 1.0% of Mn and 2.0 to 5.0% of Cr, the remainder being of Fe and inevitable impurities.

The bearing steel according to the present invention can improve on the reduction of the durability life of the bearing used under vibrations and impact loads due to high speed rotation and is practically excellently machinable as well.

The properties of the chemical components of the steel according to the present invention and the reasons for the limitations to the contents of the components will now be explained below.

C: 0.65 to 0.90%

In a rolling bearing, since a rolling element and a bearing ring (race) make a line-to-line contact (roller bearing) or point-to-point contact (ball bearing) to each other, pressure of contact is extremely high. Accordingly, it is a most important property of the rolling bearing steel that it has a high hardness not causing plastic deformation and ensures smooth movement of the bearing at the contacting portions. Further, the hardness is also required to be high in view of the abrasion resistance. Then, it is necessary that the carbon content is more than 0.65% for the reasons as described above. However, if it is present as more than 0.90%, the metallic structure is caused to change during use since the carbon diffusion rate is increased and the carbides become huge, causing stress concentration leading to the reduction of the rolling contact fatigue life as described previously. In addition, this increase in the amount of the carbides degrades the machinability. Accordingly, the upper limit is defined as 0.90%.

Si: 0.15 to 0.50%

Silicon is used as a deoxidizer upon steel refining. If deoxidization of steel is insufficient, oxide inclusions are increased in the steels, which also constitute a stress concentration course promoting the change of the metallic structure during use. For the deoxidization, at least 0.15% of silicon content is necessary. On the contrary, if it is incorporated by more than 0.50%, the amount of residual austenite after quench hardening is increased, which reduces the hardness after hardening and the rolling contact fatigue life. Further, since the lowering of the hardness after annealing is not sufficient, the machinability is degraded.

Mn: 0.15 to 1.00%

Manganese is an element used upon refining as a deoxidizer as well as silicon. Further, it is greatly effective in improving the hardenability and it is a useful element for applying complete hardening in relatively larger

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parts. For attaining these effects, at least 0.15% of manganese has to be incorporated. However, if is exceeds 1.00%, the amount of the retained austenite after hardening is increased, which reduces the hardness obtained by quench hardening and the rolling contact fatigue life.

Cr: 2.00 to 5.00%

Chromium is an important element for improving the hardenability and it restrains the change of the microstructure due to the carbon diffusion, to contribute to the improvement of the durability life. For attaining such an effect, at least 2.0% of chromium has to be present. On the other hand, if the content exceeds 5.0%, the effect is saturated and, on the contrary, workability is degraded in the steps such as rolling, forging and cutting and the material cost is increased as well.

Ni: 0.20 to 0.50%

Nickel has an effect of reinforcing the matrix to improve the toughness thereby improving the rolling contact fatigue life. For ensuring such an effect, it has to be present as more than 0.20%. However, if it is present as more than 0.50%, the amount of the retained austenite is increased to reduce the hardness obtained by quench hardening, which rather lowers the rolling contact fatigue life. In addition, since the nickel is an expensive element, excess addition may result in wasteful and increased material cost.

Mo: 0.1 to 2.0%

Molybdenum reinforces the matrix and restrains the carbon diffusion to thereby prevent the reduction of the rolling contact fatigue life due to the change of the microstructure. In order to attain such an effect, molybdenum has to be present as more than 0.1%. However, if it is present as more than 2.0%, such an effect is saturated and the workability of the steel is degraded and the material cost is increased wastefully.

V: 0.05 to 1.00%

Vanadium forms fine and stable carbides to thereby suppress the carbon diffusion and prevent the change of metallic structure during use. That is, this is an element effective for improving the rolling contact fatigue life and such an effect can be obtained by incorporating vanadium by more than 0.05%. However, if it is present as more than 1.0%, such an effect is saturated, the rolling and forging properties as well as the machinability of the steel are lowered and the material cost is increased wastefully.

N: 0.0090 to 0.0200%

As described subsequently, nitrogen chemically bonds with niobium and alumium to form nitrides thereby plays a roll for preventing the austenite crystal grains from becoming coarser. The minimum content of nitrogen corresponding to the contents of niobium and alumium described later is 0.0090%. However, if it exceeds 0.0200%, the effect is saturated and steel manufacture becomes difficult.

Al: 0.010 to 0.050%

Aluminum forms a fine nitride (AlN) in the steel which is finely dispersed in the steel to prevent austenite crystal grains from becoming coarser during heating for quench hardening. For this purpose, at least 0.010% of the content of aluminum is necessary. On the contrary, if it is present as more than 0.050%, alumina (Al_2O_3) as a non-metallic inclusion is increased which reduces the rolling contact fatigue life.

Nb: 0.005 to 0.50%

Niobium, like aluminum forms fine carbonitrides in the steel which are finely dispersed in the steel to prevent the growth of the austenite crystal grains during heating for quench hardening. For attaining this effect sufficiently, at least 0.005% of the content is necessary. However, if it is present as more than 0.50%, the effect is saturated resulting in the reduction of the workability of the steel and wasteful increase in the material cost.

S: 0.020 to 0.050%

Sulfur is dispersed as MnS in the steel. Since Mns a much softer material than steel, shear stress at a blade tip is reduced by the internal notch effect upon cutting. Further, it reduces the cutting force also by the lubricating effect at the cutting portion to thereby improve the machinability of the steel. For effectively attaining such an effect for the improvement of the machinability, sulfur has to be present at least as 0.020%. However, if it is present as more than 0.050%, sulfur chemically bonds with bismuth to hinder the hot workability. Further, the amount of MnS as the non-metal inclusion becomes excessive to lower the rolling contact fatigue life of the rolling bearing.

REM: 0.005 to 0.10%

The rare earth elements also improve the machinability and, for attaining such an effect, they have to be present as at least 0.005%. However, if they are present as more than 0.10%, the effect of improving the machinability is saturated and most of them are wastefully contained unmelted in the matrix. This also lowers the rolling contact fatigue life by reason of the change of the metallic structure described above.

Pb: 0.02 to 0.30%

Lead does not form a solid solution in the steel phase but is finely dispersed alone or together with sulfides in the steel. Since lead is also much softer than the steel, it can improve the machinability of the steel by the same effect as that of MnS. For effectively attaining such an effect of lead for improving the machinability, it

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has to be present as at least 0.02%. However, if it is present as more than 0.30%, the hot workability is reduced and the rolling contact fatigue life of the bearing steel is lowered.

Ca: 0.0005 to 0.0100%

Calcium has the effect of suppressing the diffusion abrasion of deposits, so called belark adhered on the cutting surface of tools, by which the machinability of the steel can be improved in the sense of extending the tool life. For attaining such an effect, Ca has to be present as at least 0.0005%. However, even if it is present as more than 0.0100%, such an effect is saturated, the material cost is wastefully increased and also the rolling contact fatigue life is reduced.

Bi: 0.001 to 0.200%

Bismuth is dispersed by itself into the steel to improve the machinability of the steel like lead. The minimum content necessary for attaining this effect is 0.001%. However, if it is present as more than 0.200%, the hot workability and the contact rolling fatigue life are deteriorated as in the case of lead.

Se: 0.005 to 0.20%, Te: 0.005 to 0.10%

Selenium and tellurium are elements belonging to the same group as sulfur and they improve the machinability of the steel due to the effect similar to that of sulfur. Further, they also have an effect of making the shape of MnS particle nearly spherical, thereby eliminating the factor reducing the rolling contact fatigue life, that is, by reducing crack formation from the extended top end of MnS particle if it is formed in an elongated shape. They contribute to the improvement of the contact rolling fatigue life also on this view point. Such effects can be obtained only when both of the selenium and tellurium are contained each by more than 0.005%, respectively. However, the effect is saturated to wastefully increase the material cost and lower the contact rolling fatigue life if the selenium is contained by more than 0.20% and the tellerium is contained by more than 0.10%, respectively.

EXAMPLE 1

Table 4 shows the chemical composition for the steels according to the present invention, comparative steels and conventional steels. In Table 4, steels shown by Nos. A1-A9 are steels according to the present invention; steels shown by Nos. B1-B7 are comparative steels in which one of the ingredient elements is out of range as defined in the present invention, steels shown by Nos. C1 and C2 are conventional steels in which Nos. C1 is an example of steels defined in JIS: SUJ2, while No. C2 is an example of steels defined in SAE: 5120.

A dynamic load test was applied for the steels under the conditions shown in Table 2, i.e., after application of ordinary quench hardening and tempering to control the hardness of the steel to be HRC 61-62 for the steels Nos. A1-A9 according to the present invention, the comparative steels Nos. B1-B7 and the conventional steel C1, and after application of carburizing hardening and tempering to control the surface hardness of the steel to HRC 61-62 for the conventional steel No. C2.

The test was conducted while assembling a bearing in an alternator under the conditions shown in Table 2 and the fatigue life for each of the specimens is shown in Table 5. In this table, "fatigue life" means a period of time from the beginning of the test to the occurrence of peeling.

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Table 4

No.	Chemical Composition (wt%)						
	C	Si	Mn	Ni	Cr	Mo	V
A1	0.68	0.15	0.18	0.09	2.12		
A2	0.86	0.22	0.49	0.12	2.15		
A3	0.87	0.27	0.67	0.17	4.41		
A4	0.69	0.46	0.95	0.12	4.71		
A5	0.67	0.46	0.95	0.48	4.40		
A6	0.75	0.23	0.35	0.35	3.54	1.35	
A7	0.81	0.26	0.28	0.28	3.95		0.56
A8	0.66	0.25	0.36	0.47	4.40	1.02	0.26
A9	0.87	0.16	0.18	0.12	2.10	1.93	0.48
B1	0.60	0.15	0.17	0.09	2.10		
B2	0.78	0.41	0.94	0.06	5.41		
B3	0.96	0.26	0.95	0.07	4.40		
B4	0.72	0.10	0.18	0.13	1.85		
B5	0.86	0.55	0.93	0.07	4.42		
B6	0.85	0.27	1.16	0.08	4.40		
B7	0.63	0.35	0.94	0.06	1.80		
C1	1.01	0.23	0.41	0.11	1.44		
C2	0.21	0.24	0.79	0.09	0.81		

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Table 5

No.	Fatigue life (hr)	No.	Fatigue life (hr)
A1	1133	B1	613
A2	1019	B2	1403
A3	1247	B3	909
A4	1342	B4	748
A5	1347	B5	906
A6	1488	B6	932
A7	1471	B7	744
A8	1495	C1	43, 61
A9	1411	C2	189, 202

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As apparent from Table 5, as compared with the conventional steels Nos. C1 and C2 having fatigue life of 43 to 202 hours, the steels Nos. A1-A9 according to the present invention have longer fatigue lives of 1019 to 1495 hours. Their material cost is within a reasonable range and have long fatique life and excellent practical usefulness for use in the rolling bearings.

The comparative steels Nos. B1,B3-B7 have longer fatigue lives as compared with the conventional steels Nos. C1 and C2 but are much inferior as compared with the steels according to the present invention. The comparative steel No. B2 has a fatigue life of 1403 hours which is comparable with the steels according to the present invention, but the Cr content thereof is as high as 5.41%, increasing the material cost. The machinability thereof is also poor.

Heretofore, the results of the tests as well as the confirmed effects of the steels according to the present invention which were used for bearing rings have been described. However, since the peeling occurs due to the contact between the bearing ring and the rolling element, it will be apparent that the steels according to present invention are also effective when they are used for the rolling elements (balls and/or rollers).

As apparent from the foregoing results, the bearing steel according to the present invention can dissolve the problem of the reduction of the durability life of the bearing when used under vibration and impact loads accompanying high speed rotation and is reasonable in view of the material cost and the machinability. Accordingly, it has excellent practical usefulness. In particular, it can provide an extremely effective material in those applications subject to heavy vibration and high impact loads such as in alternators.

Accordingly, the bearing steel according to the present invention can provide an excellent long durability life at a reasonable cost when it is applied, for example, to engines and auxiliary equipment driven by engines in aircraft or automobiles, in which reduction of the durability life was caused in the conventional steels with the advent of increasing rotational speed in recent years. Thus, the bearing steel in accordance with the present invention can further ensure high speed rotation and contribute greatly to the improvement of the reliability and performance of such equipment.

EXAMPLE 2

Table 6 shows chemical compositions of steels Nos. A10-A21 according to the present invention, comparative steels Nos, B8-B10 and conventional steels Nos. C3 and C2 which were subjected to a rolling life test conducted in this example. The comparative steels are those in which one of the ingredients is out of the range as defined in the present invention. The conventional steel No. C3 is an example of steels defined in JIS: SUJ2 and No. C2 is the same as steel No. C2 shown in Table 4.

For conducting a rolling life test, disk-like test specimens were at first prepared from the test steels and given a predetermined heat treatment. Table 7 shows the hardening temperature for the test steels other than the steel No. C2. Since the steel No. C2 is a case hardening steel, the temperature for the secondary hardening after applying carburization is shown in Table 7. Since the steels according to the present invention have a low carbon content and contain a relatively great amount of Cr, the hardening was conducted at a temperature higher by about 50 to 70°C than that for the conventional steels Nos. C3 and C2. The situation is the same for the comparative steels. The austenite grain size number of the test steels when they were applied with the heat treatment at the hardening temperature shown in Table 7 (values for the grain size number are accorded to JIS: G0551) is shown in the middle column of Table 7 (the crystal grain size in the surface carburized portion is shown for the case hardening steel C2).

Subsequently, tempering was applied for each of the test steels including the case hardening steel No. C2 such that the surface hardness was controlled substantially to be HRC 61-62, then a dynamic load test was conducted while rolling balls under load conditions shown in Table 2. The results are shown in Table 7. "Rolling life" shown in the table means, a period of time (hr) until the occurrence of peeling at the bearing surface from the beginning of the test.

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Table 6

No.	Chemical Composition (wt%)						
	C	Si	Mn	Ni	Cr	Mo	V
A10	0.67	0.25	0.45	0.05	3.51	0.01	0.01
A11	0.77	0.19	0.27	0.09	2.12	0.01	0.01
A12	0.69	0.39	0.32	0.10	3.87	0.05	0.02
A13	0.85	0.44	0.77	0.02	4.80	0.02	0.03
A14	0.72	0.22	0.51	0.47	3.33	1.88	0.05
A15	0.81	0.32	0.64	0.35	2.20	0.53	0.10
A16	0.72	0.20	0.40	0.39	3.58	0.09	0.31
A17	0.74	0.29	0.90	0.27	3.05	0.28	0.02
A18	0.66	0.34	0.24	0.10	3.99	1.35	0.28
A19	0.79	0.38	0.92	0.01	4.28	1.99	0.01
A20	0.84	0.26	0.15	0.41	4.93	0.02	0.03
A21	0.72	0.48	0.39	0.03	2.88	0.01	0.05
B8	0.95	0.25	0.38	0.01	3.56	0.01	0.02
B9	0.73	0.25	0.38	0.02	1.50	0.02	0.01
B10	0.60	0.26	0.46	0.20	3.39	0.01	0.01
C2	0.21	0.24	0.79	0.09	0.81		
C3	1.00	0.25	0.39	0.01	1.49	0.01	

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Table 6 (Cont'd)

No.	Chemical Composition (wt%)		
	Nb	Al	N
A 10	0.010	0.015	0.0153
A 11	0.100	0.031	0.0060
A 12		0.033	0.0170
A 13		0.035	0.0120
A 14	0.030	0.027	0.0133
A 15		0.042	0.0102
A 16		0.043	0.0090
A 17	0.011	0.029	0.0117
A 18	0.018	0.033	0.0141
A 19		0.048	0.0109
A 20		0.030	0.0078
A 21	0.022	0.037	0.0154
B 8		0.025	0.0150
B 9		0.030	0.0102
B 10		0.023	0.0170
C 2		0.030	0.0150
C 3		0.029	0.0090

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Table 7

No.	Heat treatment	Property	
	Hardening temperature (℃)	Austenite grain size number	rolling life (hr)
A10	900	11.2	1303
A11	900	11.5	1127
A12	900	10.8	1379
A13	920	11.1	1425
A14	920	10.3	1487
A15	920	10.0	1461
A16	920	10.0	1400
A17	900	11.7	1389
A18	900	11.1	1413
A19	920	10.2	1388
A20	920	10.9	1391
A21	920	11.0	1383
B8	900	10.8	604
B9	900	10.1	822
B10	920	6.8	850
C2	850 *	8.9	189, 202
C3	850	8.7	43, 61

*secondary hardening temperature

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Referring at first to the austenite grain size in Table 7, the crystal grain size in each of the steels Nos. A10-A21 according to the present invention is equal to or finer (the most fine grain size is 11.7, the most coarse grain size is 10.0 which is finer than that of the conventional steels), than that of the conventional steels Nos. C3(JIS: SUJ2) and C2 (SAE 5120), although they were applied with hardening at a temperature higher than that for the conventional steels.

From the result of the dynamic load test shown in Table 7, improved rolling life of more than 1100 hr can be attained in any of the steels Nos. A10-A21 according to the present invention. On the contrary, the rolling life of the comparative steels Nos. B8-B10 is only about 850 hours for the longest and it is extremely short in the conventional steels. As low as from several tens to 200 hours.

As has been described above, in the steels according to the present invention, since the grain coarsening can be minimized, it is possible to apply quench hardening from such a temperature that can utilize the effect of the additive element to the maximum extent for improving the rolling life. As a result, all of the steels Nos. A10-A21 according to the present invention have a sufficient rolling life under the dynamic load, respectively as shown in Table 7.

In this example, the rolling life was measured for the test steels when they were applied to the bearing rings, but it will be apparent in view of the peeling mechanism that the improved life can be obtained also in the case of using the steels according to the present invention for rolling elements (balls and/or rollers).

As apparent from the foregoing results, the bearing steel according to the present invention can provide a long durability life, in particular, under severe conditions in which vibrations and impact loads are applied. Accordingly, the bearing steel can be used as a material most suitable to bearings used under high speed rotation or bearings for engines or auxiliary equipment driven by engines such as in automobiles or aircraft inevitably subject to vibrations and impact loads. Furthermore, in the heat treatment for manufacturing such bearings, since quench hardening can be applied at a sufficiently elevated temperature or within an increased period of time without the problem of grain coarsening, this can contribute to the simplification of production steps and stable maintenance of the product quality.

EXAMPLE 3

Table 8 shows chemical compositions of the steels Nos. A22-A34 according to the present invention, comparative steels Nos. B11-B14 and conventional steels Nos. C2 and C3 used for a cutting test. In the comparative steels, one of the ingredients is out of the range as defined in the present invention. Nos. C2 and C3 are conventional steels which are the same as the conventional steels shown in Table 6.

For examining the machinability of each of the test steels, heat treatment for spheriodizing annealing was applied to a rolled bar obtained from each of the test steels and subsequently a cutting test was conducted under the following conditions.

Tool:	SKH 4
Biting depth:	1 mm
Feed rate:	0.2 mm/rev
Cutting rate:	50 m/min
Cutting Oil:	none

If the flank wear of a tool, i.e. the loss of relief of a tool behind the cutting edge is VB.

The tool life was defined as a time at which VB=0.3 mm. The results for the cutting test are shown in the left column of Table 9. As can be seen from the results, all of the steels Nos. A22-A34 according to the present invention show longer tool life than that of the conventional steels Nos. C2 and C3.

Next, for conducting a rolling life test, a predetermined heat treatment was applied so as to set the surface hardness of the test steels to be HRC 61 to 62. Then, a rolling test piece was produced and a dynamic load test was conducted on the test piece while rolling balls under the loading conditions shown in Table 2. The results are shown in Table 9. In the table, "rolling life" means a period of time (hr) until the occurrence of peeling at the bearing surface from the beginning of the test.

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Table 8

No.	Chemical Composition (wt%)						
	C	Si	Mn	Ni	Cr	Mo	V
A22	0.69	0.25	0.40	0.02	2.31	0.01	0.02
A23	0.73	0.33	0.85	0.01	3.50	0.02	0.02
A24	0.88	0.26	0.54	0.03	3.59	0.01	0.01
A25	0.65	0.17	1.00	0.01	4.53	0.01	0.01
A26	0.71	0.44	0.56	0.01	3.71	0.02	0.07
A27	0.70	0.28	0.37	0.03	4.76	0.43	0.01
A28	0.89	0.31	0.72	0.25	2.98	0.02	0.01
A29	0.82	0.24	0.49	0.38	3.15	0.01	0.10
A30	0.66	0.26	0.23	0.41	4.01	0.91	0.03
A31	0.70	0.38	0.83	0.01	3.44	1.05	0.13
A32	0.73	0.42	0.35	0.21	3.71	1.31	0.08
A33	0.68	0.19	0.34	0.37	2.63	0.12	0.56
A34	0.83	0.48	0.39	0.44	4.76	0.25	0.73
B11	0.97	0.27	0.39	0.39	3.34	0.02	0.11
B12	0.83	0.61	0.39	0.44	4.76	0.25	0.73
B13	0.74	0.33	0.85	0.01	3.50	0.24	0.02
B14	0.96	0.26	0.95	0.07	3.55	0.01	0.01
C2	0.21	0.24	0.79	0.09	0.81		
C3	1.00	0.25	0.39	0.01	1.49	0.01	

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Table 8 (Cont'd)

No.	Chemical Composition (wt%)						
	S	REM	Pb	Ca	Bi	Se	Te
A22	0.044						
A23	0.010	0.02					
A24	0.029					0.02	
A25	0.011			0.0030			
A26	0.015						0.01
A27	0.010	0.09					
A28	0.016					0.03	
A29	0.036		0.11				
A30	0.032			0.0023			
A31	0.025				0.01		
A32	0.047	0.02				0.01	
A33	0.009			0.0045	0.009		
A34	0.013	0.02	0.04				
B11	0.015		0.12				
B12	0.023	0.05	0.04				
B13	0.030	0.02		0.010			
B14	0.017						
C2	0.018						
C3	0.016						

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Table 9

No.	Property	
	tool life (hr)	rolling life (hr)
A22	53	1156
A23	78	1323
A24	77	1112
A25	103	1421
A26	62	1382
A27	99	1433
A28	130	1138
A29	146	1301
A30	121	1469
A31	137	1473
A32	122	1489
A33	154	1229
A34	150	1231
B11	131	913
B12	179	821
B13	184	723
B14	40	909
C2		189, 202
C3	32, 40, 38	43, 61

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As can be seen from the result of the dynamic load test shown in Table 9, a long life of more than 1100 hr can be attained in all of the steels Nos. A22-A34 according to the present invention. On the contrary, the life of the comparative steels Nos. B11-B14 is about 900 hr for the longest and the life of the conventional steels is extremely short from several tens to 200 hours.

As described above, the steels according to the present invention have excellent machinability and show extremely satisfactory values for the rolling fatigue life even under dynamic load conditions. The comparative examples in which one of the ingredients is out of the range as defined in the present invention have a sufficient performance in view of the machinability, but the result of the rolling life test under the dynamic loads show that such steels are not suitable to applications in use for those portions undergoing impact shocks and vibrations as in automobiles.

In this example, the rolling life of the test steels was measured using them as bearing rings, but it will be apparent, in view of the peeling mechanism, that the steels according to the present invention can also provide a long life when they are used as rolling elements (balls and/or rollers).

As apparent from the foregoing results, the bearing steels according to the present invention can provide a long life under severe conditions, in particular undergoing vibrations and impact loads. Accordingly, they can be used as a material most suitable to bearings used under high speed rotation or bearings for engines and auxiliary equipment driven by engines, for example, in automobiles or aircraft which are inevitably put under vibrations and impact shocks. In addition, since the machinability is improved, in the steels according to the present invention, the cutting speed can be increased in the cutting step upon manufacturing the bearings, etc., or in a case where the cutting fabrication is applied at an identical speed with that in the conventional case, the tool life can be increased. Therefore, cost reductions can be made in the production steps in any of the cases. Further, since the steels according to the present invention are excellent also in view of the disposability of cutting dusts, shavings, swarf, etc., troubles caused in the steps due to entangling of cutting dusts can be reduced.

Claims

1. A bearing steel comprising, by weight, 0.65 to 0.90% of C, 0.15 to 0.50% of Si, 0.15 to 1.0% of Mn, 2.0 to 5.0% of Cr, and optionally one or more of 0.20 to 0.50% of Ni, 0.1 to 2.0% of Mo, or 0.05 to 1.0% of V, the remainder being Fe and inevitable impurities.

2. A bearing steel comprising, by weight, 0.65 to 0.90% of C, 0.15 to 0.50% of Si, 0.15 to 1.00% of Mn, 2.0 to 5.0% of Cr, 0.0090 to 0.0200% of N, one or more of 0.010 to 0.050% of Al and 0.005 to 0.50% of Nb, and optionally one or more of 0.20 to 0.50% of Ni, 0.10 to 2.00% of Mo and 0.05 to 1.00% of V, the remainder being Fe and inevitable impurities.

3. A bearing steel comprising, by weight, 0.65 to 0.90% of C, 0.15 to 0.50% of Si, 0.15 to 1.00% of Mn, 2.0 to 5.0% of Cr, one more of 0.020 to 0.050% of S, 0.005 to 0.10% of rare earth element, 0.02 to 0.30% of Pb, 0.0005 to 0.0100% of Ca, 0.001 to 0.200% of Bi, 0.005 to 0.20% of Se and 0.005 to 0.100% of Te, and optionally one or more of 0.20 to 0.50% of Ni, 0.10 to 2.00% of Mo and 0.05 to 1.00% of V, the remainder being Fe and inevitable impurities.

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FIG.1

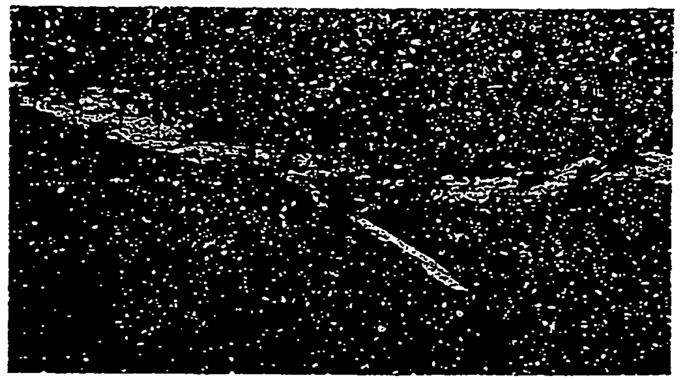
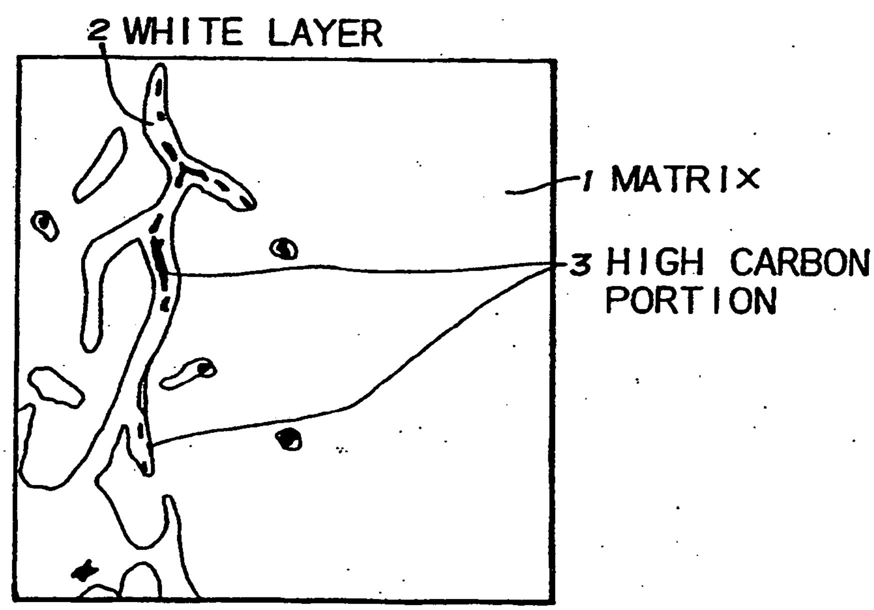


FIG.2



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EUROPEAN SEARCH REPORT

Application Number

EP 91 30 4700

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	US-A-3 929 523 (KINOSHI et al.) * Claims 1-3 * & FR-A-2 204 191	1	C 22 C 38/18 C 22 C 38/22 // F 16 C 33/62 F 16 C 33/30
X	GB-A-1 408 218 (UGINE ACIERS) * Claims 1,2,4 * & LU-A-67 275	1,2	
A	SU-A- 120 526 (IVANOV et al.) * Complete document *	1	
A	SU-A- 226 858 (GUZMAN et al.) * Complete document *	1	
A	GB-A-2 155 951 (AICHI STEEL WORKS LTD) * Claims 1-9 *	1-3	
A	GB-A-2 200 369 (NIPPON SEIKO K.K.) * Claims 1-12 *	1-3	
A	US-A-3 945 821 (STROUP) * Complete document *	1-3	TECHNICAL FIELDS SEARCHED (Int. Cl.5) C 22 C F 16 C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	22-08-1991	LIPPENS M.H.

CATEGORY OF CITED DOCUMENTS

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